

Advanced Reflectance Standards for Monitoring Climate Change Forces

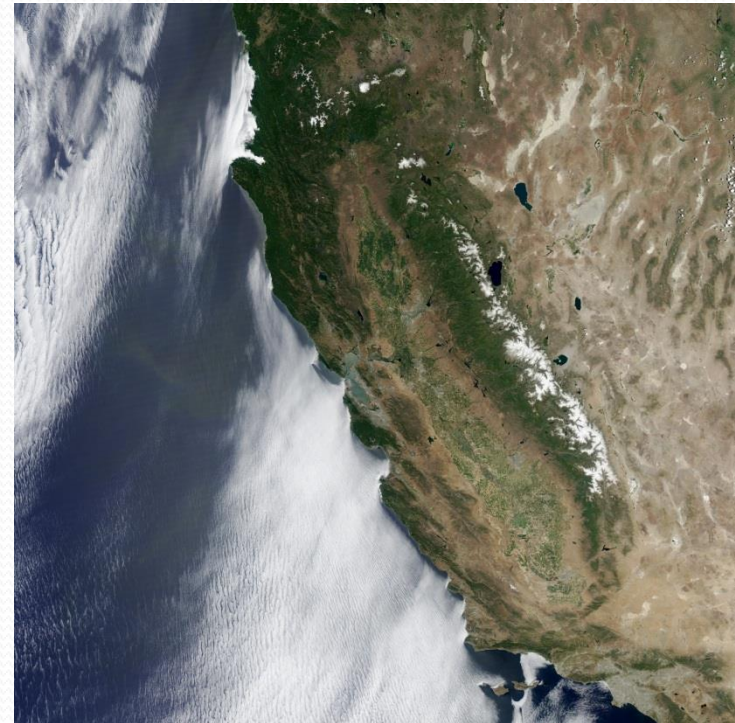
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Reflectance and Climate Science

Why is Reflectance Important?

- Overall Earth Albedo (reflectance) important in determining net warming or cooling due to solar radiation
 - High albedo: snow, cloud cover
 - Low albedo: forest, dark pavement
 - Angle dependent albedo: water
- Spectral composition of Albedo used in
 - Atmosphere: water vapor, cloud properties, aerosols
 - Ecology: chlorophyll, leaf water, pigments
 - Geology: mineral and soil types
 - Coastal Waters: chlorophyll, phytoplankton, organic materials and sediments
 - Snow/Ice: snow cover fraction, grain size, melting
 - Biomass Burning: smoke, fires
 - Commercial: mineral exploration, agriculture, forest production

earthobservatory.nasa.gov



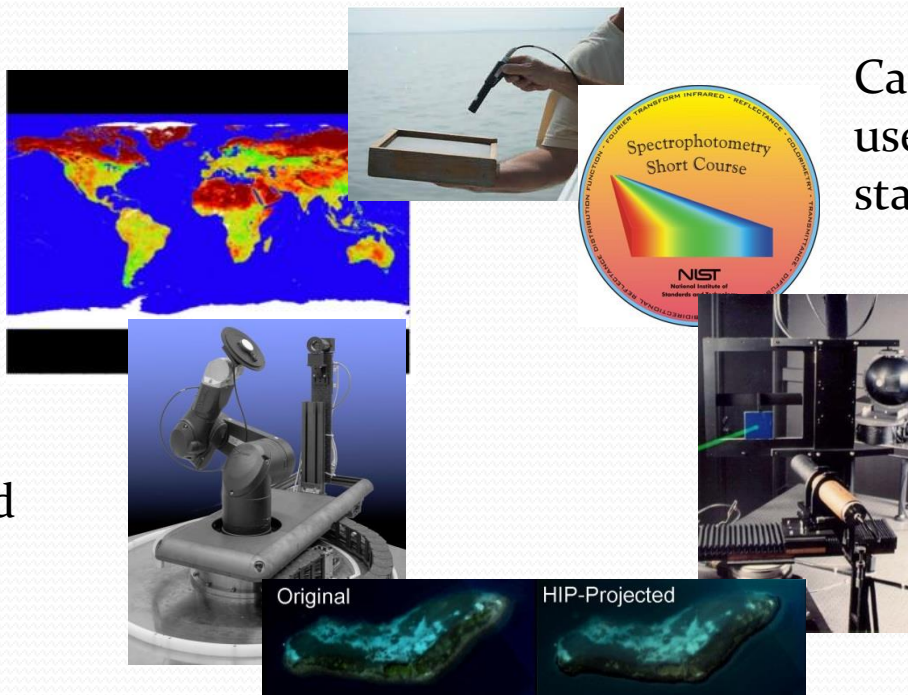
NIST's role:

- Disseminating reflectance scale
- Insuring SI traceability of reflectance measurements
- Providing techniques, models and tools for remote sensing community

Objectives

SCATMECH for modeling materials and scattering

New facilities: ROSI and hyperspectral imaging/projection



Calibration and use of reflectance standards: STARR

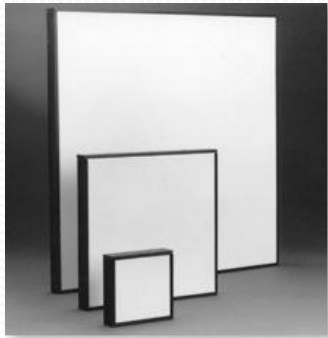
- To facilitate the monitoring of climate change forces through:
- Dissemination of the reflectance scale
 - Improved capabilities for the characterization of reflective and scattering materials
 - Improved theoretical understanding of reflective and scattering materials



Dissemination of the Reflectance Scale

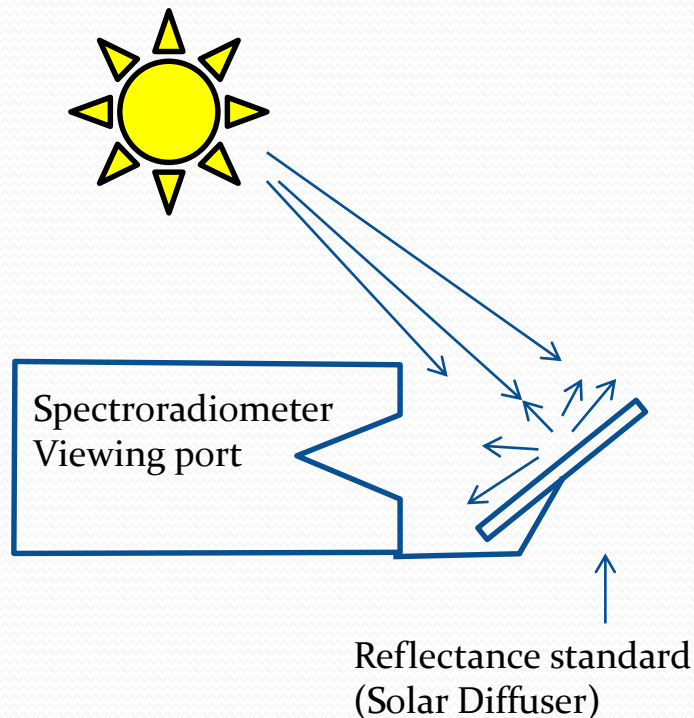
Spectral Tri-function Automated Reference Reflectometer (STARR)

- Primary source of reflectance calibrations for US for nearly 20 years
- Disseminate scale through calibration of reflectance standards
 - Yearly calibration of standards for NASA/GSFC
 - Provides traceability to diffusers used in satellites
- Three measurement geometries :
 - Directional-hemispherical (250 nm to 2500 nm)
 - Specular (250 nm to 2500 nm)
 - In-plane, bidirectional (250 nm to 1100 nm^{*})

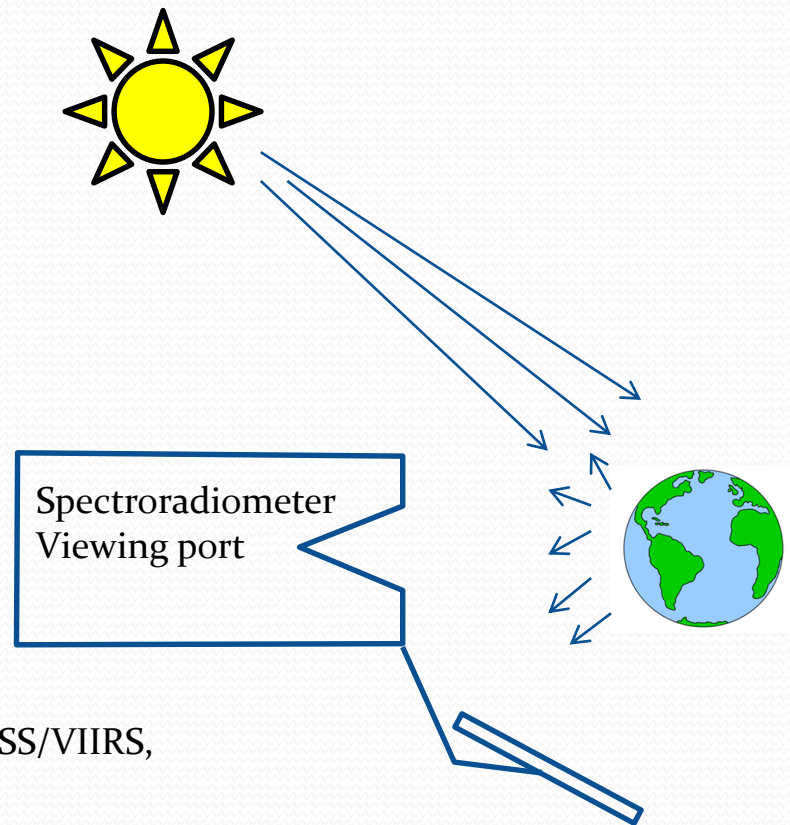


Use of Reflectance Standards: On-orbit

1. View solar diffuser

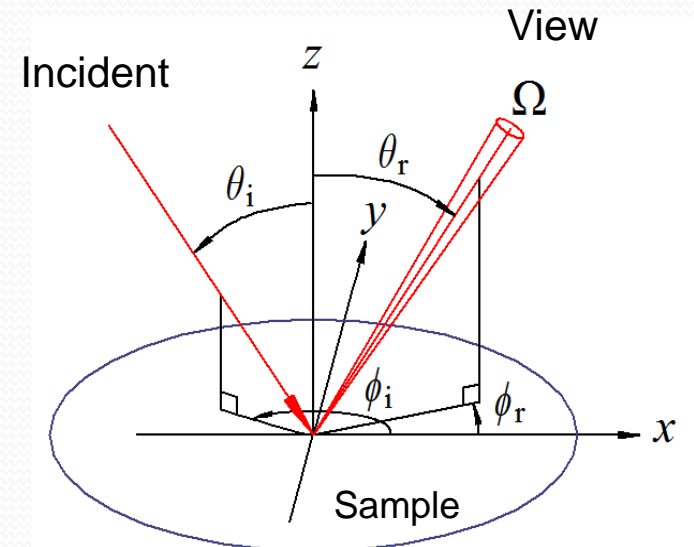
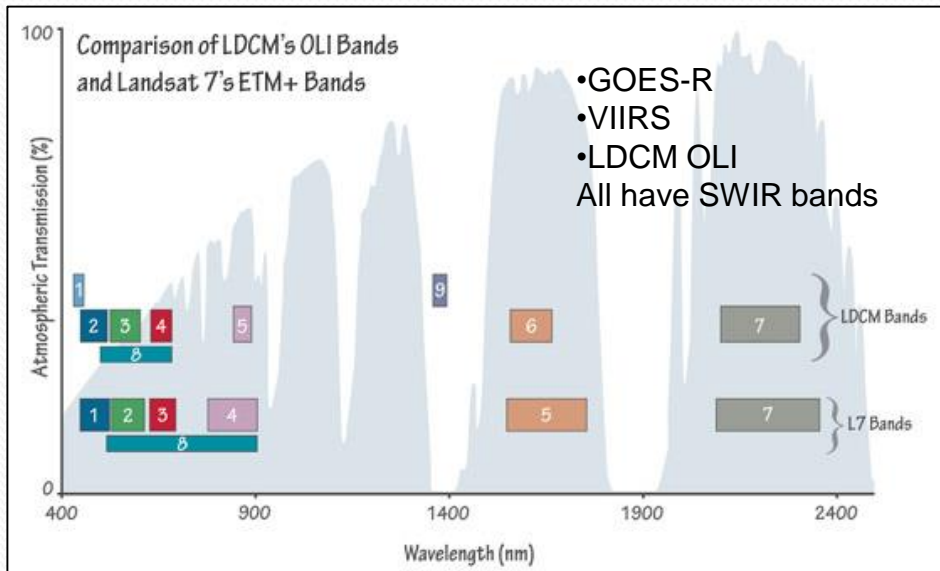


2. View Earth



- Solar diffuser on satellite (MODIS, LDCM, NPOESS/VIIRS, CLARREO...)
- Compare earth radiance to diffuser radiance, Sun as common source
- Part of calibration/validation for satellite spectroradiometer

Meeting Research Challenges



STARR: in-plane only ($\phi_i = 180^\circ$ and $\phi_r = 0^\circ$)

ROSI: out-of-plane, any combination of θ_i , ϕ_i , θ_r and ϕ_r

Research Challenges

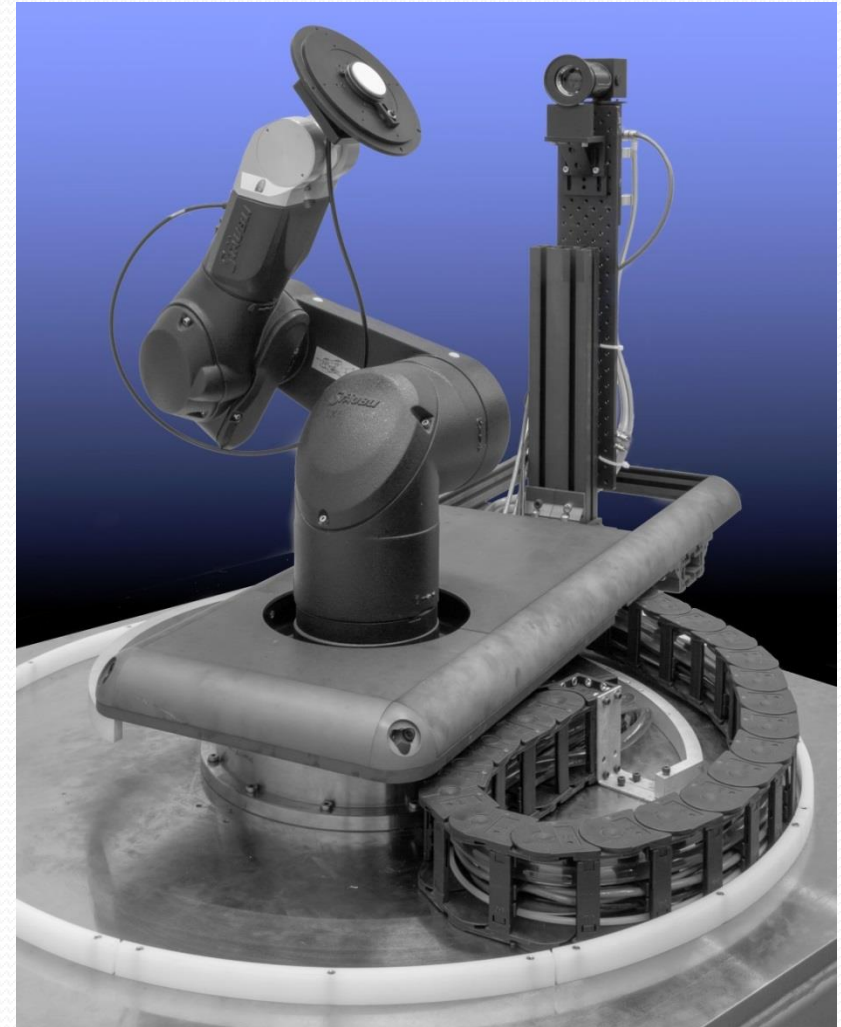
- **Spectral range:** growing need to cover the full solar reflective region
 - In the past, bidirectional measurements beyond 1100 nm for STARR limited by availability of detectors with sufficient signal-to-noise ratio and linearity
- **Out-of-plane geometries** to match use of standards in practice

Research Approach

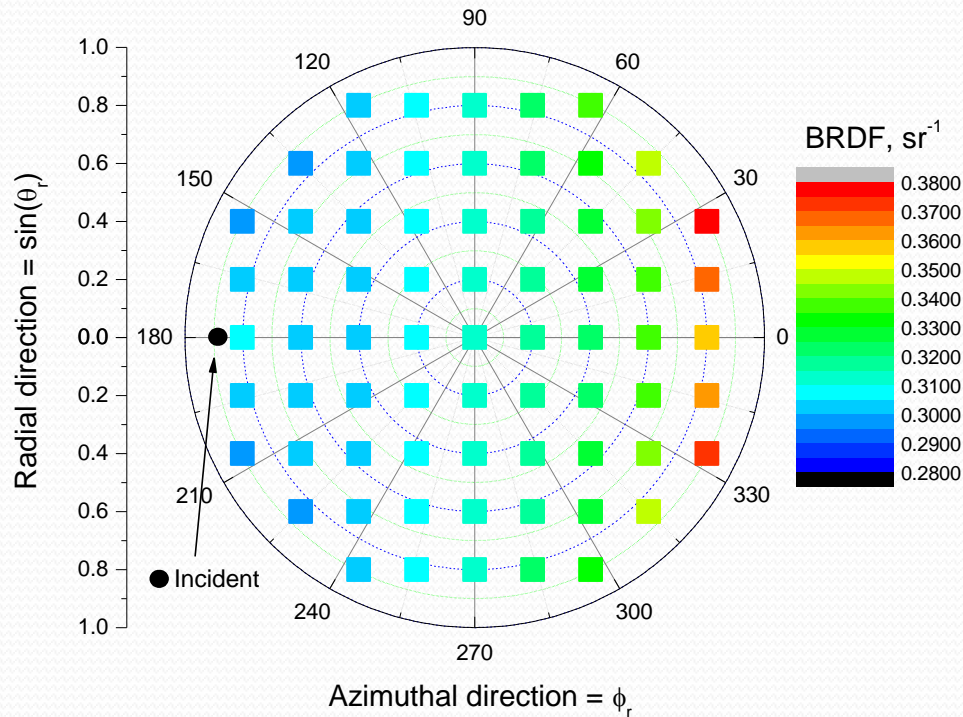
- ✓ Expand STARR measurement capability from 1100 nm to 2500 nm for o/45 geometry using low noise, 4-stage ex-InGaAs detector
- ROSI: next-generation reference reflectometer with multi-angle, out-of-plane measurement capability

Robotic Optical Scatter Instrument (ROSI)

- New facility for multi-angle spectral reflectance
- Currently 480 nm to 2500 nm tunable operation, with wavelengths to 250 nm integrated fall 2014
- Full out-of-plane capabilities
- Improved sample handling
- Simultaneous operation of silicon (UV-NIR) and ExInGaAS (SWIR) detectors

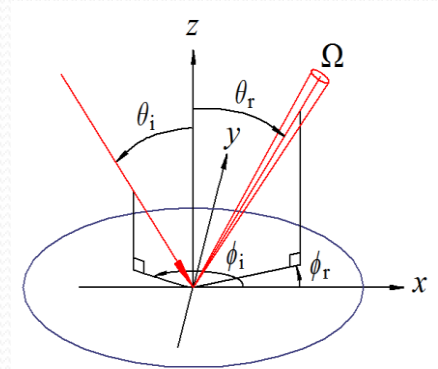


Hemispherically-scanned viewing with ROSI



Fixed incident at
 $\theta_i = 60^\circ$ and $\phi_i = 180^\circ$

Vary view angles
both θ_r and ϕ_r



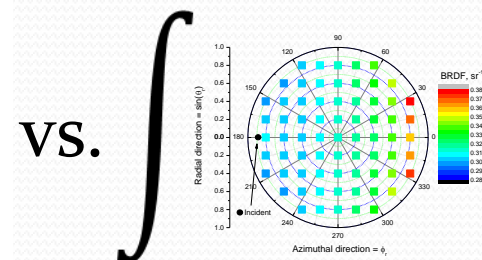
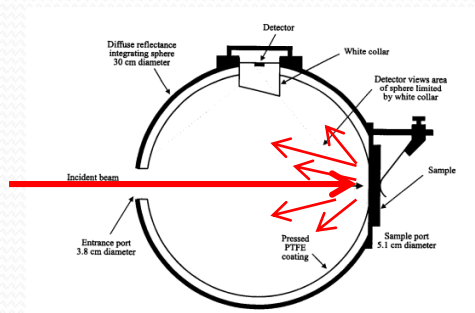
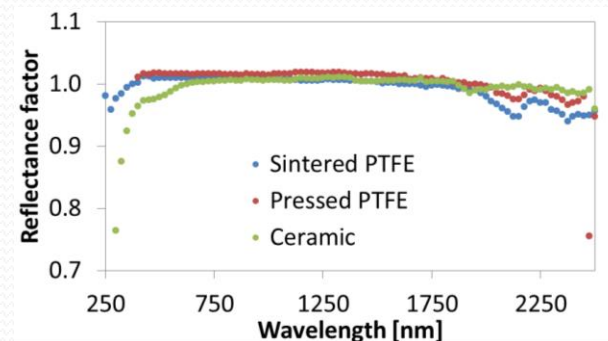
- BRDF varies with polar (θ_r) and azimuthal (ϕ_r) viewing angles
- At fixed θ_r , BRDF varies with ϕ_r
 - In-plane view $\theta_r = 36.9^\circ$ $\phi_r = 0^\circ$, ($x = 0.6$, $y = 0$), $\text{BRDF} = 0.3367 \text{ sr}^{-1}$
 - Rotate view 90° $\theta_r = 36.9^\circ$ $\phi_r = -90^\circ$ ($x = 0$, $y = -0.6$) $\text{BRDF} = 0.3122 \text{ sr}^{-1}$
- Illustrates the need to calibrate samples in geometry that will be used by customer!

Research Focus Areas

- UV-induced reflectance changes
 - Reflectors subject to UV i.e., during space flight
 - Limited knowledge of effect
 - NIST SPHERE collaboration on UV aging
- Enhanced standards
 - New materials
 - Flatter spectral response, durability, etc.
 - Publish broader spectral range for 0:45 pressed PTFE
- Validation hemispherical reflectance using multiple methods
 - Compare sphere-based and integrated angle-scanning methods
 - Update reference values
 - Increased confidence and lower uncertainties



NIST SPHERE (Simulated Photodegradation by High Energy Exposure)
http://www.nist.gov/el/facilities_instruments/integrating_sphere_fac.cfm

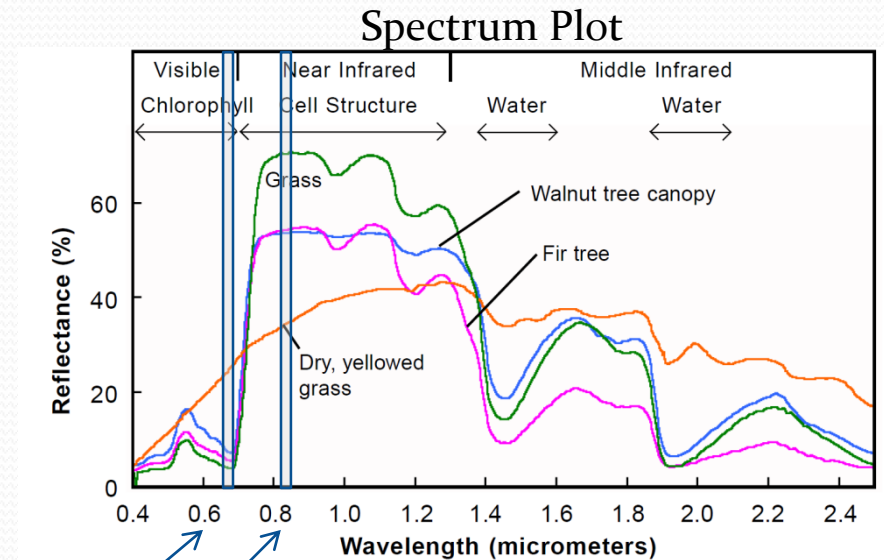
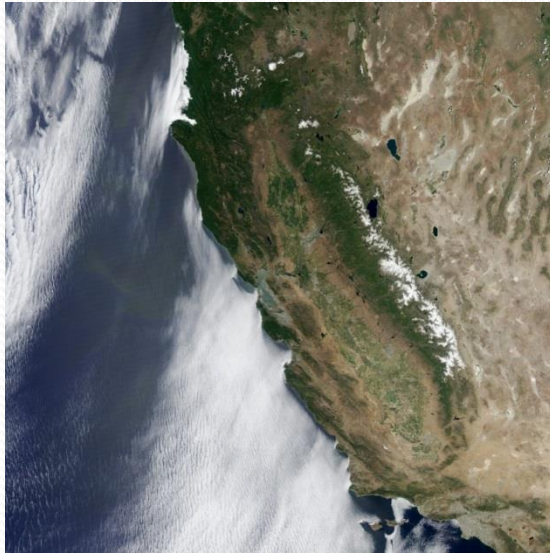




Improved Capabilities for the Characterization of Reflective and Scattering Materials

- 
- Robotic Optical Scatter Instrument (ROSI)
 - Hyperspectral Imaging Microscope
 - Hyperspectral Image Projector (HIP)

What is hyperspectral imaging?

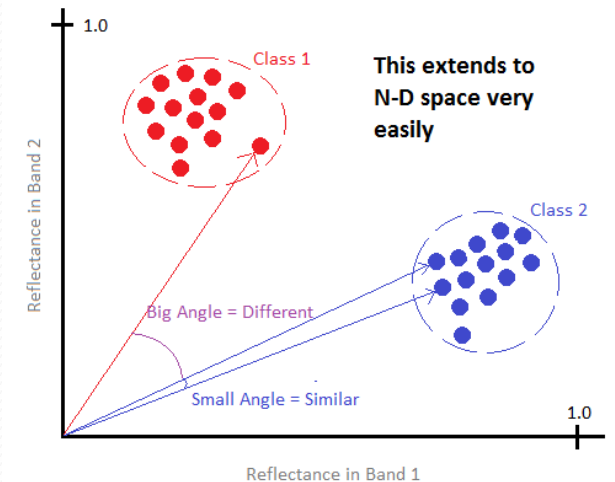


Band 1

Band 2

- Hyperspectral imagers give a spectrum for each pixel
- Resolution matters
- Simplify classification of pixels by grouping into those with like reflectance combinations
 - Easy to visualize in 2-D
 - Hyperspectral “n-D” improves differentiation of components
- Use to estimate biomass, vegetation health, leaf water, etc.
- Many algorithms exist
- Accuracy of algorithms difficult to quantify

Scatter Plot: 1 pt = 1 pixel



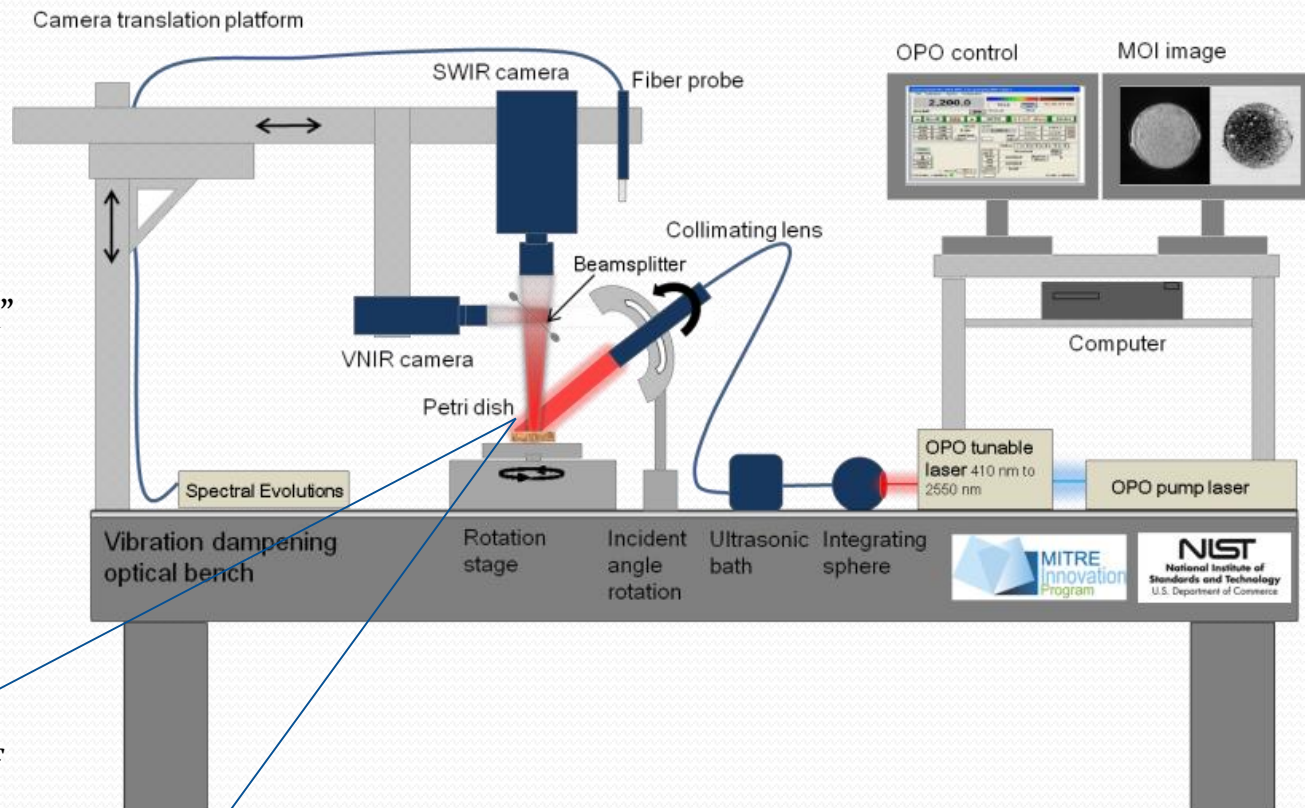
NIST OPO based hyperspectral imaging microscope

Research Challenge

- Validating pixel classification algorithms
- Ability to produce scenes with known “ground-truth” and measure their spectral signatures

Research Approach

- Assemble microscenes with known components
- Measure microscene spectra with hyperspectral microscope
- Use HSI microscope to develop standard datasets and evaluate performance of algorithms on known scenes



- Broadband camera views sample under a microscope
- Tunable laser (Optical Parametric Oscillator - OPO) illuminates sample
- A reflectance image is collected at each wavelength, from 405 nm to 2500 nm
- The resulting high resolution data cube can be representative of materials viewed by remote-sensing hyperspectral imagers in the field

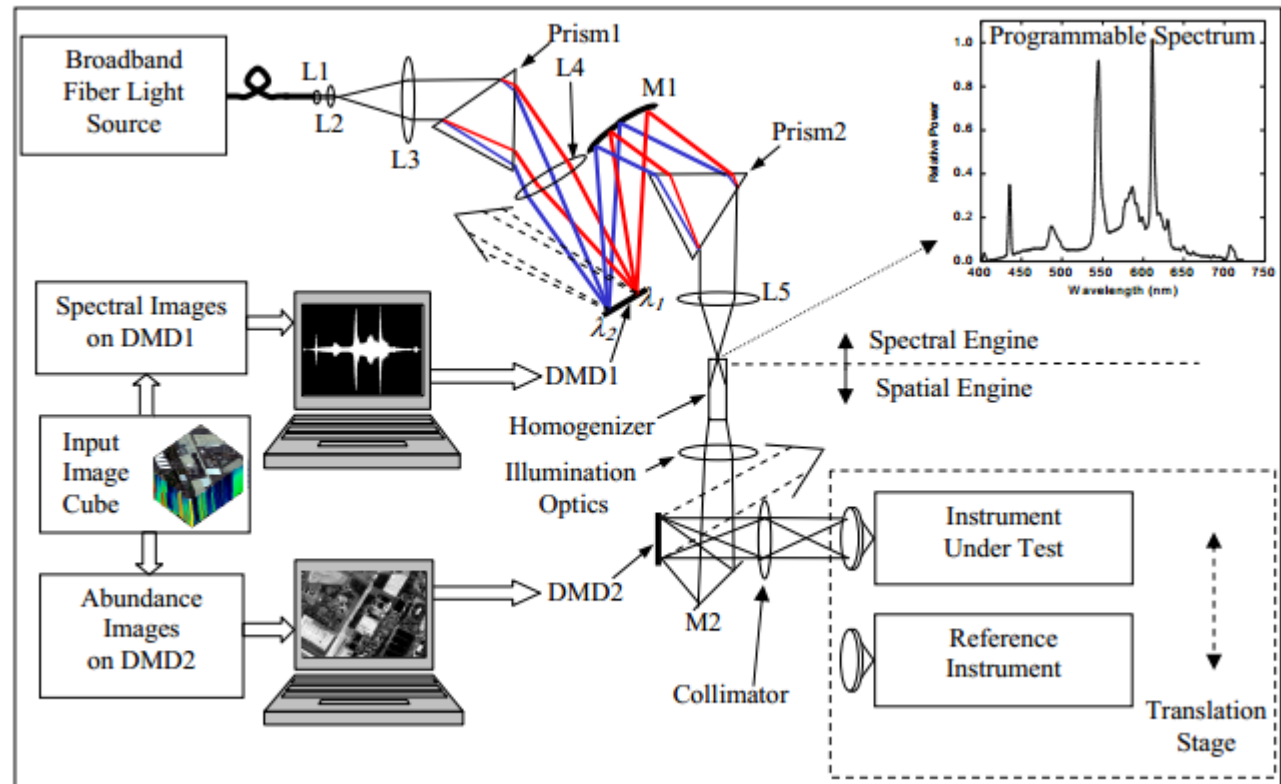
NIST Hyperspectral Image Projector (HIP)

Research Challenge

- Need to provide changing, realistic scenes for testing imagers in a laboratory environment

Research Approach

- Use airborne hyperspectral images and/or microscene hyperspectral images as input cube
- Project using HIP
- Use to help validate biomass estimators using projected scenes
- Potential calibration service for hyperspectral imagers



Original and HIP-projected images of a coral reef

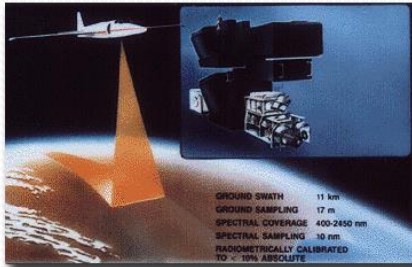
Desired Future Outcomes

From the Hyperspectral Microscope:

- Validation of biomass-data retrieval algorithms by using known/standard scenes
- Reference spectral data sets for biomass materials with measured spectral distributions

From the Hyperspectral Image Projector (HIP):

- Validation of biomass data as retrieved from sensor/algorithms by using projected scenes
- Capability to provide performance testing of hyperspectral imaging systems
 - such as AVIRIS and HypsIRI (see below)
- Calibration service for hyperspectral imagers




Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)

- Existing aircraft-based hyperspectral imager
- <http://aviris.jpl.nasa.gov/>

Hyperspectral InfraRed Imager (HypsIRI)

- Future satellite-based hyperspectral imager
- Will enable global biomass surveys of land vegetation
- <http://hyspiri.jpl.nasa.gov/>





Improved theoretical understanding of reflective and scattering materials

SCATMECH: Polarized Light Scattering C++ Class Library

<http://pml.nist.gov/scatmech>

Software library provides tools for light scattering calculations, including:

- Polarization
- Optical properties of materials
- Thin film optics
- Optical scatter models (23)
- Diffraction grating models

Library is free and in the public domain.

Non-Frames Version

SCATMECH:
Table of Contents

Home
Introduction
Classes and Functions

- Polarization
- Optical properties of materials
- Free-space scattering models
- Grating models
- Surface scattering models
- Property models
- Utility

Example Programs

- BRDFProg
- RCNProg
- ReflectProg
- MieProg

Conventions
Console Interface
Writing Your Own BRDF_Model
Compiling the Library
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Register

SCATMECH > Classes and Functions > Surface Scattering Models > Bobbert_Vlieger_BRDF_Model

class Bobbert_Vlieger_BRDF_Model

The Bobbert_Vlieger_BRDF_Model implements the theory of Bobbert and Vlieger for the scattering by a sphere on a substrate. The theory applies to a sphere of total radius r having a coating of thickness d of a distance δ above a surface having a dielectric coating. The optical constants (functions) of the substrate, sphere, and sphere coating, are n_0 , n_1 , and n_2 , respectively. The theory is exact, although care must be taken to choose appropriate operating parameters, and convergence should always be checked. This class does not inherit the properties of `Spherical_Particle_BRDF_Model`, since it does not account for an arbitrary stack of films on the substrate.

With Version 5.02, the single dielectric film (shown in diagram above as having thickness t and index n_1) was replaced by an arbitrary stack of films.

Parameters:

Parameter	Data Type	Description	Default
lambda	double	Wavelength of the light in vacuum [μm]. (Inherited from <code>BRDF_Model</code> .)	0.532
type	int	Indicates whether scattering is evaluated in reflection (0) or transmission (1). (Inherited from <code>BRDF_Model</code> .)	0
substrate	dielectric_function	The optical constants of the substrate, expressed as a complex number (n, k) or, optionally, as a function of wavelength. (Inherited from <code>BRDF_Model</code> .)	(4.05, 0.05)

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Frames Version

SCATMECH:
Polarized Light Scattering C++ Class Library

SCATMECH is an object-oriented C++ class library developed to distribute models for light scattering applications. Included in the library are models for diffuse surface scattering that predict the bidirectional reflectance distribution function (BRDF), codes for calculating scattering by isolated particles, and codes for reflection, transmission, and diffraction from gratings. Emphasis has been given to those diffuse scatter models which are physics-based and which predict the polarization properties of the scattered light. The library also includes a number of classes that may be useful for working with polarized light or the optics of thin films. The library is constructed to enable expansion of new models.

Current Version

Download version 6.00 (February 2008)
See version history

Author

Thomas A. Germer

Modeled Integrated Scatter Tool (MIST)

The MIST program has been developed to provide users with a general application to model an integrated scattering system. The program performs an integration of the bidirectional reflectance distribution function (BRDF) over solid angles specified by the user and allows the dependence of these integrals on model parameters to be investigated. The models are provided by the SCATMECH library of scattering codes. See [MIST Website](#) to download.

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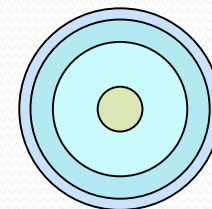
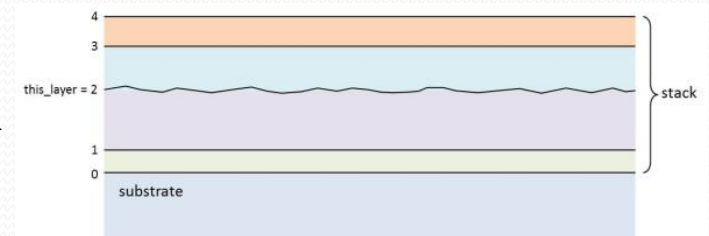
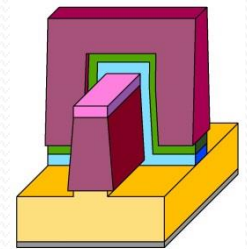
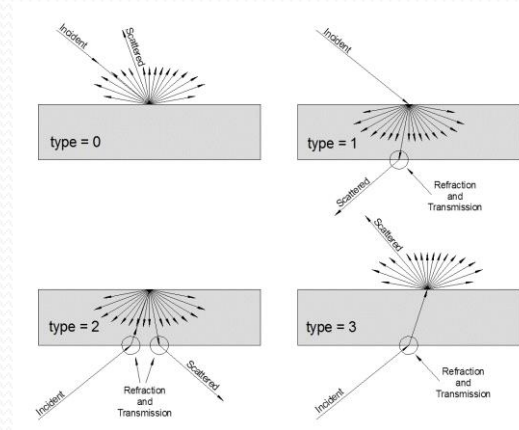
Library is designed to work with larger programs for ray tracing, image rendering, and simulation.

Socket for light scattering models enables others to add models without modifying SCATMECH or user program.

Current version: 6.01 (May 2008)

SCATMECH Version 7

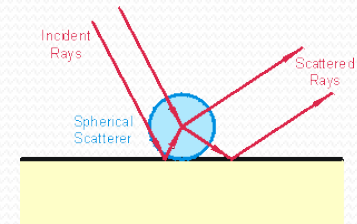
- Planned release Fall 2014
- New features:
 - Most BRDF models will have transmission and upwelling modes.
 - Rigorous coupled wave analysis for 2D gratings
 - Enhanced codes for scattering in multilayer dielectric coatings.
 - Multilayer-coating Mie scattering



SCATMECH Applications

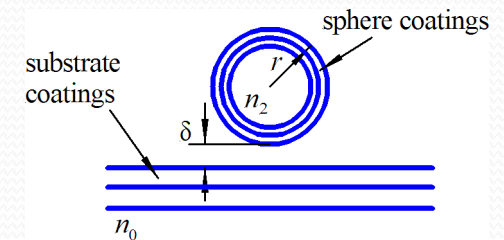
- Many models are valid in specific limits:
 - Roughness in the smooth surface limit
 - Roughness in the facet approximation
 - Volume scattering
 - Particle scattering

These codes are useful for estimating scatter levels in optics, appearance modeling, material characterization, etc.

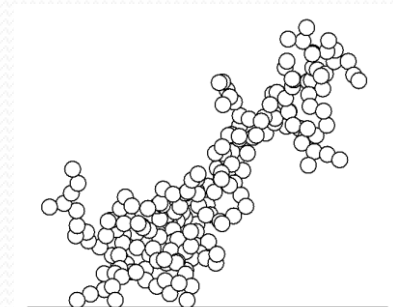


- Some give “exact” solutions to Maxwell’s equations
 - Sphere on a surface
 - Sphere in free space (Mie scattering)
 - Binary gratings

Used for metrology applications: dimensional metrology benchmarks for more general (finite element, FDTD, etc.) codes



- Future models in development
 - Fractal aggregated clusters in aerosol and on surfaces
 - Radiative transfer in highly diffuse anisotropic materials (such as skin or clouds with aligned ice crystals)





Summary and Future Challenges

Summary

- Supporting future needs for traceability and reflectance dissemination through materials studies and expansion of reflectance capabilities
- Commissioning of ROSI facility and comparisons of 0:45 bidirectional reflectance with STARR underway
- Recent installation of Hyperspectral microscopy facility and use of HIP expanding capabilities to increase accuracy in biomass estimation and other remote sensing data products
- SCATMECH provides tools for calculation of light scattering for metrology and materials characterization

Future Challenges

- Enhanced materials for reflectance standards and meeting customer needs for expanded calibration wavelengths and geometries
- Establishing accuracy in remote sensing biomass algorithms
- Capabilities for performance testing of hyperspectral remote sensing systems
- Model development for clusters in aerosols and on surfaces

Acknowledgements and Links

Clarence Zarobila

Christopher White, Eric Byrd, and Deborah Stanley

Ronald Resmini, Robert Rand, Christopher Deloye, Jeffrey Stevens

Spectrophotometry short course:

http://www.nist.gov/pml/div685/sc/spectrophotometry_course.cfm

Spectrophotometry: Accurate Measurement of Optical Properties of Materials, Thomas A. Germer, Joanne C. Zwinkels, and Benjamin K. Tsai, Eds., Volume 46 in *Experimental Methods in the Physical Sciences* (Academic Press, New York, 2014).

http://www.nist.gov/pml/div685/grpo3/spectrophotometry_starr.cfm

<http://www.nist.gov/pml/div685/grpo6/starr2.cfm>

<http://www.nist.gov/pml/div685/grpo4/hip.cfm>

http://www.nist.gov/pml/div685/grpo6/scattering_scatmech.cfm



Thank you!